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Dear Doc:

After our several recent discussions on optical systems, I feel that I might perform a service for you by putting together a short memo on this subject. I hope this material will be something you can hand to Mr. B and Gene for their information as well.

Image-forming optical systems of the photographic type divide themselves rather neatly into three kinds. Of these, the refracting system is by far the most common. This system employs only lenses for the formation of the image. For systems of short focal length and reasonable speed, refracting systems are much the simplest of the three both in their computation and in their construction.

When refracting systems are used under conditions of temperature and pressure, varying significantly from the conditions under which they are manufactured, the problem of maintaining focus becomes serious. Temperature variations affect the index refraction of the glass as well as the physical dimensions of both the glass and the mechanical mounting. The index of refraction of the air is a function of both temperature and pressure and, since the lens is immersed in the air, the air's index is an important quantity. In many refracting systems, the length of the lens barrel or the distance from the front of the front element to the back of the back element may approach the focal length of the system. This has a direct disadvantage in that the overall length of the system, unless it is made telephoto, from focal plane to front surface, may be considerably more than the focal length. A secondary disadvantage arises because the long barrel lengths require very large first and last elements if a significant field is to be covered.

The second type of image-forming system is one made completely with mirrors. This is called a reflecting system and is typified by large telescopes. These systems, because of the lack of flexibility in the design of reflecting surfaces, cannot be made to cover very large fields without extreme complication. As the speed of the system increases this difficulty becomes rapidly even more complex. A few multiple surface reflecting systems are known which do cover good fields with relatively fast speeds, but all such systems known to us have the characteristic in common that their physical dimensions are very great compared to their effective focal lengths. One such system is contained in a volume approximately cub in shape, each edge of which is about two focal lengths.

The third type of optical system is called catadioptric. This word means simply, 'the combination of lenses and reflecting surfaces for the formation of images'. It is not to be confused with systems which contain folding mirrors whose sole purpose is to change the direction of the light path and do not contribute to the formation of the image except in a derogatory fashion. The "A" cameras were all straight refracting systems, the "B" camera is a simple refracting system with a single folding mirror, while the "C" system was a direct catadioptric system complicated additionally by many folding mirrors.

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The very great advantage of catadioptric systems is that the primary optical power is obtained by mirrors which are free of color errors, are very much less temperature dependent than lenses and can be made with great optical power without great weight. The material for the mirrors need not be of high optical quality and so can be chosen for other desirable characteristics such as low temperature coefficient of expansion, low density or ease of manufacture. Nearly all catadioptric systems have developed from the initial proposal of Schmidt in which he suggested that the great simplicity of a spherical mirror, when combined with a very weak refracting correcting plate, could be made to produce excellent images over a wide field at a fast  $f$  number.

Much more sophisticated catadioptric systems developed from the same principle, however, and having many of the same advantages, have been evolved since the time of Schmidt. A family of systems having the primary image formation accomplished by mirrors and the image correction for high acuity accomplished by lenses, some large and in the entrance pupil and some small near the focal plane, have been developed in recent years. The Flugge system, which we chose a while ago as a likely candidate for our problem, is a catadioptric system without folding mirrors. It has the advantage of very short barrel length, good control of focus because most of the power resides in the mirrors, and an attractive mechanical mount since the elements are separated over a maximum distance of something less than the focal length. The tube need be made only as long as its diameter and, thus, is quite stiff.

One of the principal disadvantages of a normal Schmidt and the Bouwers modification, which is typical of the catadioptric systems recently tested by the Navy, is that the heavy weights, the primary mirror and the correcting lens are at the opposite ends of a tube whose length is nearly equal to the focal length of the system but whose diameter is quite small compared to its length. These systems have been made in very long focal lengths, and, thus, are physically quite long, making them sensitive to internal structural vibrations. I think our experience with the "C" camera has indicated to us the extreme difficulty of precision optical systems spread out over long mechanical distances. This camera was also plagued with one of the most serious objections to the straight refracting system since the transfer lens was extremely temperature sensitive with regard to its focal length.

In our approach to the current problem, we have tried to find and examine systems in which the position of the focus was principally controlled by reflecting surfaces, the mechanical structure was short and rigid compared to the focal length, and for which refracting optical components provide enough flexibility in the design to permit the highest quality of imagery. I do not believe that the images of the Flugge system, as manufactured, will be as close to their theoretically predicted quality as might be the case of a Schmidt or a true refracting system, but under operating conditions the Flugge is less subject to vibration and variations of temperature and pressure, and thus variations of focus; consequently, I believe that such a system will perform better than some of the others we have considered. This feeling is particularly strong with respect to long focal length systems which must be folded by flat mirrors in order to be contained in the space envelope with which we must deal.

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I hope that this discussion will make some of these considerations clearer to you.

Sincerely,